DINGO: A PILE LOAD TEST DATABASE

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ABSTRACT Prediction of pile performance often relies upon full-scale pile load testing to better manage geotechnical uncertainty and enable less conservative design. Many analysis methods (e.g. the α-method) require a load test database for calibration. Databases of these tests can provide detailed design guidance in specific geological deposits. However, full scale tests are expensive, and the results, for a variety of reasons, are not always shared with the wider geotechnical community. The DINGO database is an openly accessible database of full-scale pile load tests carried out in UK soils. This paper reports on the building of the database as well as the challenges involved and lessons learnt in collecting and sharing the pile test data. The pile test data in the database is presented by sorting for 'Geological Deposit', 'Construction Decade' and 'Construction Type'. A preliminary classification of the quality of information contained in the database is also presented.

1. Introduction

1.1 Databases in geotechnical engineering

Geotechnical engineers have historically had to deal with 'data scarcity' when developing and calibrating geotechnical design rules and guidance. While much progress has been made refining geotechnical analysis techniques since Terzaghi and Peck (1948), less progress has been made on calibrating the factors of safety used in routine geotechnical designs (e.g., Vardanega and Bolton 2016). Kulhawy and Mayne (1990) presented a comprehensive collection of correlations of simple geotechnical parameters with more complex ones. However, correlations to estimate key parameters such as undrained shear strength or effective friction angle, while useful, are best used to assess 'parameter uncertainty' (cf. McMahon 1985).

It is difficult to know reliably the accuracy of an analytical approach, such as a prediction of pile capacity, without full-scale test data. This information is much rarer and more expensive to acquire than geotechnical data on individual design parameters. In his Rankine Lecture Randolph (2003) stated that engineers 'may never be able to estimate axial pile capacity in many soil types more accurately [on the average] than about ±30%'. To quantify this accuracy reliably pile load test databases are needed. Reliability-based design approaches have been held back in the past by the lack of geo-databases for model calibration purposes (cf. Phoon 2017).

From July 2017 to June 2019 the Engineering and Physical Sciences (EPSRC) funded project 'Databases to INterrogate Geotechnical Observations' (DINGO) (Vardanega 2017) was conducted at the University of Bristol. The database hereafter referred to as the 'DINGO database' is available online via the data.bris repository (Vardanega *et al.* 2019).

1.2 Load test databases for foundation design

Pile load test databases have been employed by various researchers to calibrate methods to predict pile behaviour. For example, Skempton (1959) used a database of pile load tests in London Clay to calibrate the 'α-method' for total stress pile design. Patel (1989, 1992) updated this calibration for modern laboratory and pile testing methods. More recently, Yang *et al.* (2015) discusses the collection of a load test database (Yang *et al.* 2016) to calibrate design methods in sands.

Similar databases have been used to calibrate factors for design codes. Paikowsky (2003) used a database of tests across the United States to calibrate resistance factors for load and resistance factor design (LRFD). Databases have been built by state departments of transport such as in Louisiana (Rauser and Tsai 2016) to provide more local calibrations of resistance factors. A similar exercise was carried out in Egypt (AbdelSalam *et al.* 2015) and recently Phoon and Tang (2019) collected pile test data from many existing databases for the purpose of calibrating various reliability-based design (RBD) methods.

The aforementioned pile load test databases are by no means exhaustive and others include those reported in Patek *et al.* (2016), Lemnitzer and Favaretti (2013) and Galbraith et al. (2014). These resources, including the recently developed DINGO database, can also be used to calibrate analytical models for pile foundations such as those described in Crispin *et al.* (2019).

1.3 Study aims

This paper has the following aims:

(a) To present a summary of the sources of information that were used to assemble the DINGO database and the challenges encountered during the database assembly (Section 2) (for further information refer to Vardanega *et al.* 2019).

(b) Briefly summarise the data in the DINGO database by: 'Data Origin', 'Geological Deposit', 'Construction Decade' and 'Construction Type' (Section 3).

(c) Classify the data quality of the information in the DINGO database (Section 4).

2. Building the DINGO Database

2.1 Sources

When building a database for model calibration purposes it is essential that the database has sufficient data to adequately represent the soil conditions one seeks to model future pile designs in. In addition, it is important that the pile test data is accompanied by adequate geotechnical and geological information so that model parameters can be sensibly estimated and so that ranges for parametric studies can also be reasonably assigned. Figure 1 shows a pile load test plotted from a database record with the general geology shown.

The DINGO database contains data digitised from published papers, reports and dissertations as well as data collected from datasets donated by engineering consultants (see Vardanega *et al.* 2019 for full list of the data sources). Some challenges encountered by the research team included (but not limited to):

(i) absence of detailed geological information for individual pile tests. In some cases, general descriptions of the ground at a site had to be used instead.

(ii) difficulties establishing the exact location of individual pile tests. Missing locations had to be inferred from the project name or address given in the original data source.

(iii) difficulties establishing a site datum (the position of the geological record with relation to the pile record). Often a site datum was not available and had to be assumed to be at ground level or determined approximately using UK Grid Reference Finder (2020).

2.2 Structure

The structure of the DINGO database is 'inspired' by the Association of Geotechnical and Geoenvironmental Specialists (AGS) Data Format (AGS 2017). The information in the database is structured under three main headings (Table 1).

Figure 1 Visualisation of data related to pile 'TP2' on site 'R37_07' from the DINGO database

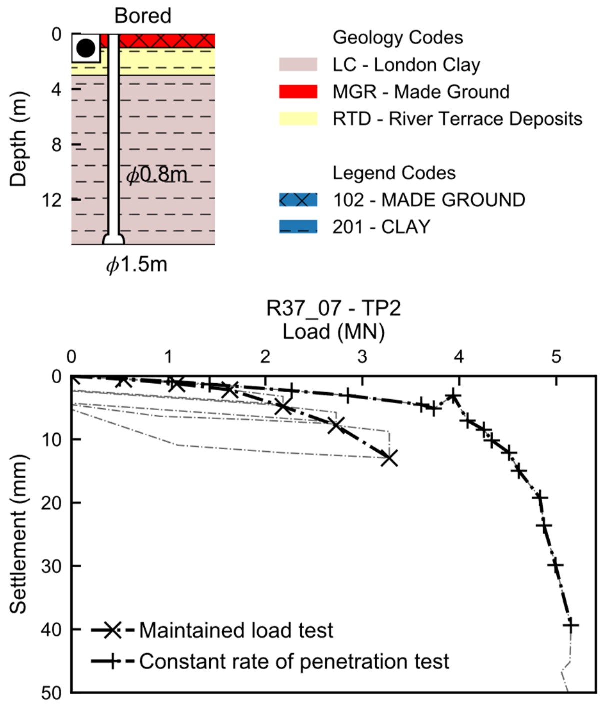


Table 1 DINGO database information structure (summarised from Vardanega *et al.* 2019)

Heading	Description
General	Project information e.g. name of source and date (or approximate date) of pile testing
Site	Site investigation data i.e. location and site geology and boreholes
Pile	Installation and test data i.e. construction material, type, load-settlement curves etc

3. Database summary statistics

3.1 Data Sources

The DINGO database currently comprises over 500 pile records. (Vardanega *et al.* 2019) with approximately 60% of the data sourced from the literature and around 40% from industrial sources.

3.2 Geographical spread

Figure 2 shows the approximate locations of the piles in the DINGO database. A large portion of the data is concentrated in the London area although there is a reasonable spread of data around major cities such as Birmingham, Manchester, Leeds and Cardiff as well as from road projects.

3.3 Geological deposit

Figure 3 shows the number of database entries for the following six significant subcategories which were identified during analysis of the database (Table 2). Piles in 'Cohesive Deposits' was the largest geological subcategory with over 260 entries. It should be noted that some piles will fit into more than one category e.g. 'London Basin' and 'Cohesive Deposits'.

3.4 Construction decade

Figure 4 shows the number of piles in the database sorted by construction decade. Most of the pile tests in the DINGO database were conducted in the 1970s.

3.5 Construction type

Figure 5 shows the number of piles in the database sorted by construction type. The most common category is, perhaps unsurprisingly, bored piles. The 'Misc' category includes less common installation methods, such as bored displacement piles, screw displacement piles and various cast-in-situ driven pile solutions. Most of the piles in the DINGO database were circular or square piles with some instances of hexagonal or H-section piles. Most of the tested piles were straight shafted with some under reamed and some tapered (see Vardanega *et al.* 2019 for more information).

Figure 2 Geographical spread of the DINGO database. Pile Construction Type indicated on the map (for the full set of maps see Vardanega *et al.* (2019))

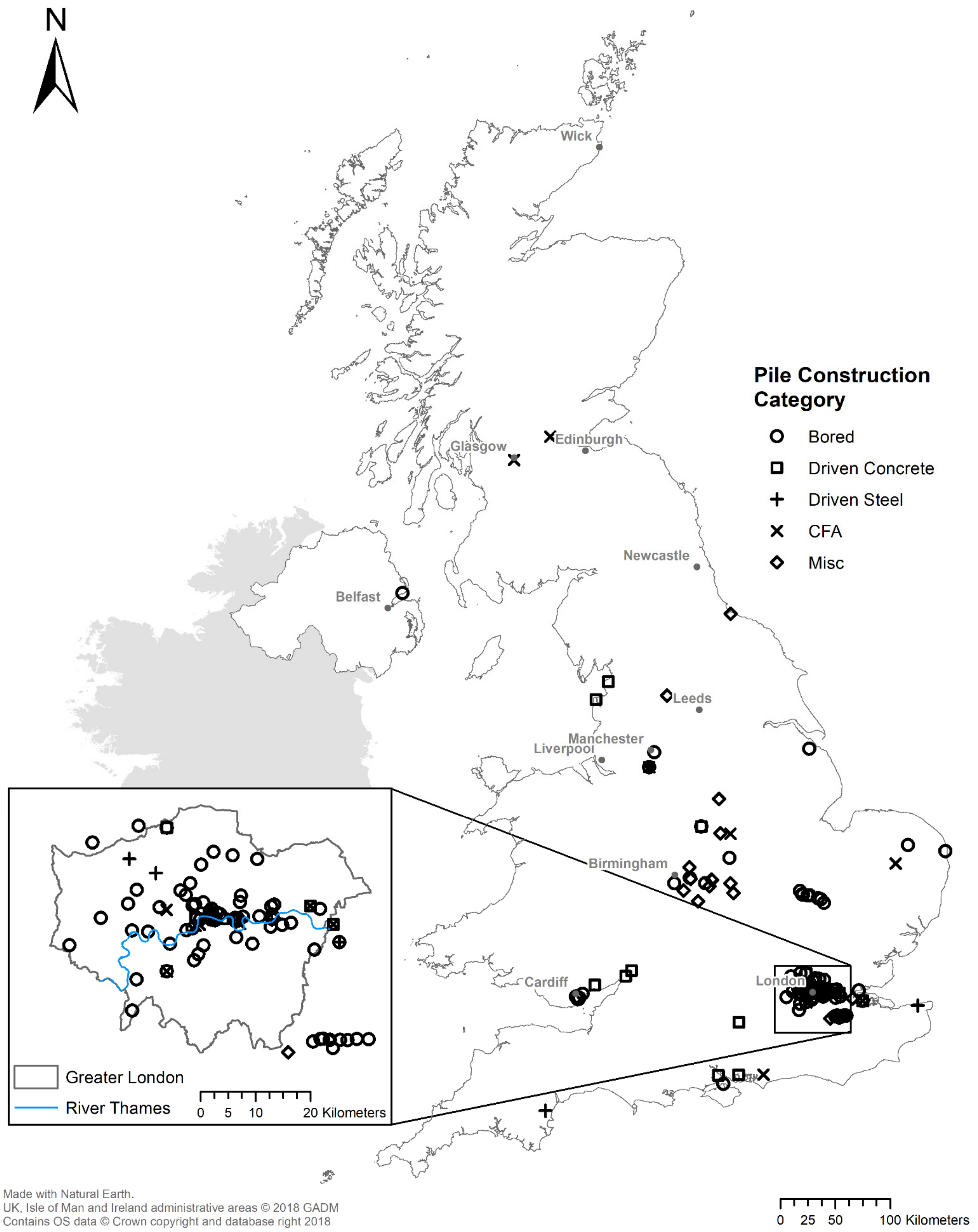


Figure 3 Number of piles by geological deposit

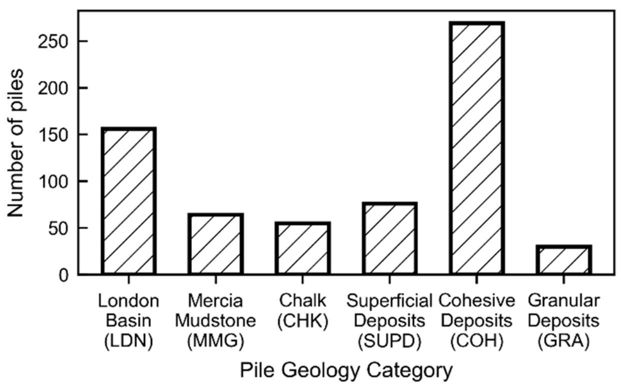
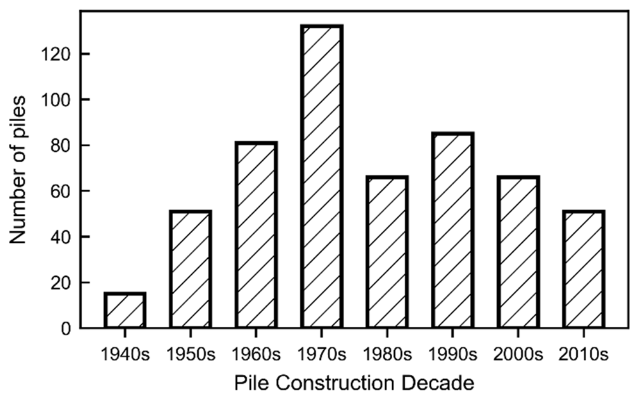


Table 2 Significant geological subcategories in the database (summarised from Vardanega *et al.* (2019))

CODE	Description
LDN	Any length of pile in London Clay, Lambeth Group or Thanet Sand
MMG	Any length of pile in Mercia Mudstone
CHK	Any length of pile in Chalk
SUPD	≥ 70% of the pile length is in superficial deposits
COH	≥ 70% of the pile length is in fine grained soils (clays and silts)
GRA	≥ 70% of the pile length is in granular soils (sands and gravels)

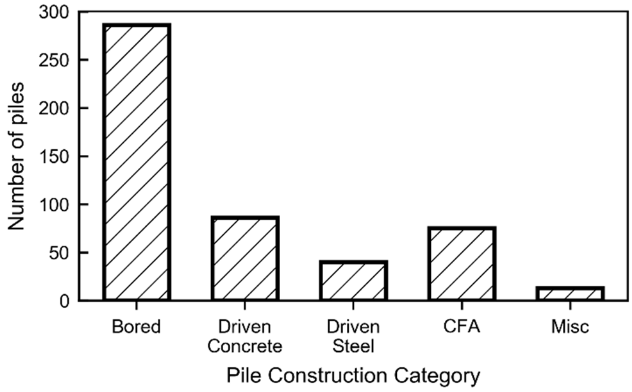
Figure 4 Number of piles by construction decade



4. Assessment of data quality

When compiling a database from multiple sources the amount and quality of data will vary. This variation influences the analyses that may be reliably performed using the data. Poulos (1989, 1999) provide a classification system for different levels of pile analysis/design. In this framework the 'method of parameter determination' is matched with the 'characteristics' of the model (shown in Table 1 in Poulos 1989). Poulos (2004)

Figure 5 Number of piles by construction type



gives a risk rating method for determining the factor of safety (through geotechnical reduction factors) for pile capacity design. Several of the factors included in the risk rating are explicitly related to the geotechnical data availability and quality, therefore the quality of the site data directly impacts the factor of safety that can be employed (Poulos, 2004).

Scenarios may arise where a more sophisticated analysis technique is available but there is insufficient data to use it in a deterministic sense. A stochastic approach or reliability-based approach could be considered in these cases using a database such as DINGO. Therefore, the tests have been categorised by the quality of data available to predict settlement or capacity (Table 3). The highest quality data available with a pile test was site specific laboratory strength test data in deposits where high-quality deformation data was also available in the literature. However, for some piles only soil description and/or geology information was available. In these cases, model parameters must be selected from similar sites using engineering judgement.

Table 3 Data quality categories in the DINGO database

Category	Description
I	Soil descriptions and geology used to select parameters from similar tests (highly reliant on engineering judgement)
II	In situ strength test data
III	Site specific laboratory strength test data
IV	Site specific laboratory strength test data and high-quality deformation data available from the same deposit

If an engineer were performing a simple 'α-method' calculation for bored pile capacity in London Clay (LDSA, 2017) it would be advisable to limit the analysis to scenarios where at least Category II (Table 3) data were available. In this case, even if a value of α established from load testing were available, a sensible estimate of the shear strength profile is needed. When using the DINGO database to calibrate analytical models, considerations of the data category (quality) available are important. It should be remembered that this database was developed based on pile load test information and therefore is not a substitute for a geological database such as the open access data of the British Geological Survey (BGS) (BGS, 2020) or comprehensive site investigation.

5. Summary

This paper has described the compilation and publication of the DINGO database for use by the UK Geotechnical Community. The database is available for download from the data.bris website (Vardanega *et al.* 2019). In this paper, the building of the database has been summarised. The number of piles in the database has been presented by 'Geological Deposit', 'Construction Decade' and 'Construction Type'. A preliminary classification of the data quality in the DINGO database has been presented. While the DINGO project was able to produce a database of over 500 pile load tests often accompanied by site investigation data, there remains a need for improved data sharing by the geotechnical community if databases such as the DINGO database are to expand.

6. Data availability statement

The DINGO database can be freely downloaded from the data.bris repository via the following weblink: https://doi.org/10.5523/bris.3r14qbdhv648b2p83gjqby2fl8 (Vardanega et al. 2019).

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8. References

AbdelSalam SS *et al.* (2015) A database to ensure reliability of bored pile design in Egypt. *Proceedings of the Institution of Civil Engineers – Geotechnical Engineering* 168(2): 131-143.

Association of Geotechnical and Geoenvironmental Specialists (AGS) (2017) Electronic Transfer of Geotechnical and Geoenvironmental Data, Edition 4.0.4. Bromley, Kent, UK.

British Geological Survey (BGS) (2020) National Geosciences Data Centre. https://www.bgs.ac.uk/services/ngdc/home.html (accessed 09/04/2020).

Crispin JJ *et al.* (2019) Prediction of pile settlement using simplified models. *Proceedings of the XVII ECSMGE-2019: Geotechnical Engineering foundations of the future* (Icelandic Geotechnical Society (eds.)). Icelandic Geotechnical Society, Iceland. 8pp.

Galbraith AP *et al.* (2014) Uncertainty in pile resistance from static load tests database. *Proceedings of the Institution of Civil Engineers - Geotechnical Engineering* 167(5): 431-446.

Kulhawy FH and Mayne PW (1990) Manual on estimating soil properties for foundation design. *EL-6800 Research Project 1493-6*, Final Report, August 1990.

London District Surveyors Association (LDSA) (2017) Guidance notes for the design of straight shafted bored piles in London Clay. LDSA Publications, London, UK.

Lemnitzer A and Favaretti C (2013) FindaPile.com. http://www.findapile.com/ (accessed 09/04/2020).

McMahon BK (1985) Geotechnical design in the face of uncertainty. *Australian Geomechanics Journal* 10(1): 7-19.

Paikowsky SG (2003) Practical lessons learned from applying reliability methods to LRFD for the analysis of deep foundations. *Proceedings of the international workshop on limit state design in geotechnical engineering practice, LSD 2003.* (Phoon *et al.* (eds.)). World Scientific, Singapore. 9pp.

Patek K *et al.* (2016) *FHWA Deep Foundation Load Test Database Version 2.0 User Manual*. FHWA (US Federal Highway Administration), Washington DC, USA. Report FHWA-HRT-17-034.

Patel DC (1989) *A Case Study of the Shaft Friction of Bored Piles in London Clay in terms of total and effective stress*. MSc thesis, Imperial College of Science and Technology, London, UK.

Patel DC (1992) Interpretation of Results of Pile Tests in London Clay. *Piling Europe*, Thomas Telford, London, UK.

Phoon KK (2017) Role of reliability calculations in geotechnical design. *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards* 11(1): 4-21.

Phoon KK and Tang C (2019) Effect of extrapolation on interpreted capacity and model statistics of steel H-piles. *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards* 13(4): 291-302.

Poulos HG (1989) Pile behaviour – theory and application. *Géotechnique* 39(3): 365-415.

Poulos, HG (1999) Common procedures for foundation settlement analysis – are they adequate? *Australian Geomechanics Journal* 34(1): 13-38.

Poulos HG (2004) An approach for assessing geotechnical reduction factors for pile design. *Proceedings of the 9th Australia New Zealand Conference on Geomechanics Auckland, New Zealand* (New Zealand Geotechnical Society and Australian Geomechanics Society (eds)), vol. 1, pp. 109–115.

Randolph MF (2003) Science and empiricism in pile foundation design. *Géotechnique* 53(10): 847-875.

Rauser J and Tsai C (2016). Beneficial use of the Louisiana Foundation Load Test Database. *Transport Research Board 95th Annual meeting*. Washington DC, USA. 17pp.

Skempton AW (1959) Cast-in-situ bored piles in London clay. *Géotechnique* 9(4): 153–173.

Terzaghi K and Peck RB (1948) *Soil mechanics in engineering practice*, Wiley, New York, NY, USA.

UK Grid Reference Finder (2020) https://gridreferencefinder.com/ (accessed 09/04/2020).

Vardanega PJ and Bolton MD (2016) Design of geostructural systems. *ASCE-ASME Journal of Risk and Uncertainty in Engineering Systems, Part A: Civil Engineering* 2(1): 04015017.

Vardanega PJ (2017) Databases to INterrogate Geotechnical Observations (DINGO). Grant reference *EP/P020933/1*, Engineering and Physical Sciences Research Council, Swindon, UK.

Vardanega PJ *et al.* (2019) *The DINGO Database: Summary Report: June 2019, v1.0*. University of Bristol, Bristol, UK, https://doi.org/10.5523/bris.3r14qbdhv648b2p83gjqby2fl8

Yang ZX *et al.* (2015) A new and openly accessible database of tests on piles driven in sands. *Géotechnique Letters* 5(1): 12-20.

Yang Z *et al.* (2016) A comprehensive database of tests on axially loaded piles driven in sand. *Zhejiang University Press Co. Ltd. Published by Elsevier Inc.*